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ABSTRACT

A review of studies on chaos theory suggests that some elements of the theory (systems, fractals, initial effects, and bifurcations) may be applied to classroom learning. Chaos theory considers learning holistic, constructive, and dynamic. Some researchers suggest that applying chaos theory to the classroom enhances learning by reinforcing systemic approaches to human interactions, encouraging cultural diversity as beneficial, and reaffirming theoretical notions of intelligence as dynamically multidimensional without linear progression. Other researchers believe that chaos theory cannot be applied to human learning systems; instead many of these researchers suggest social constructivism as a more appropriate model. The paper demonstrates applications of chaos theory using systems, fractals, initial effects, and bifurcations. A final section discusses models of learning, highlighting Piagetian theory and theoretical models. The paper concludes that more important than a model is the development of a perspective encompassing both the theory and its applications, and that researchers should explore the application of chaos theory to classroom learning before trying to construct a satisfactory model. (SM)

Chaos in the Classroom:
An Application of Chaos Theory

by

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# Chaos in the Classroom: An Application of Chaos Theory

When a butterfly flutters in Brazil, it can cause a storm system in Texas. The "butterfly effect", was graphically recorded by meteorologist Edward Lorenz in 1961 to explain weather forecasting. The analogy of initial effects, small disturbances causing large effects, is particularly powerful. As a result, the analogy is applied to natural and human systems other than the meteorological system.

Chaos theory was synthesized theoretically by Prigogine and Stengers (1984) and popularized by James Gleick (1987). As a result, the general public was introduced to systems theory and dynamic equilibrium in which a condition seeks stability through constant change. Concepts of complexity, variability, and unpredictability have replaced notions of simplicity, regularity, and predictability.

Chaos, a simplification of the theoretical construct, can be defined as an event, behavior, or process which is variable, nonlinear, and unpredictable. Although chaos exists with identifiable patterns and boundaries, the patterns as well as the boundaries are flexible and indeterministic, changing unpredictably (Pool, 1989). The importance of chaos theory is its explanatory power to understand the behavior of diverse systems. What has, through observation and experimentation, seemed random and unpredictable and, therefore, been categorized as error or divergence, is now understood as representative of patterned behavior. Thus, chaos theory will be enhanced and applications will become more frequent and diverse as chaos is perceived beneficial to examine patterns within a system.

The premise of this paper is the "butterfly effect", the sensitive dependence on initial conditions, and other theoretical elements of chaos theory including systems, fractals, and bifurcations, may be applied to the educational system and classroom learning. Instead of dissecting and analyzing components of learning, chaos theory suggests learning is holistic, constructive, and dynamic. .

## Theoretical Assumptions

Chaos theory can be described by its theoretical elements. Major elements of chaos are systems, fractals, initial effects, and bifurcations, which are summarized.

### Systems

Chaos is characterized by several features of a system–it exists in nonlinear, open systems which may be simple or complex, random or stable. Chaos theory applies to nonlinear, unpredictable systems; since most systems are nonlinear and unpredictable, chaos exists in nearly all natural and human systems (Duit & Komorek, 1994). Chaos, avoided because it was thought unreliable, uncontrollable and unpredictable, is the condition of the world and must be explored.

Chaos theory is also the perception of the world as an open system. The world is composed of interrelated parts; therefore, change in one area creates change in another. As with ripples in the water or movement of a crowd, change is ongoing with unpredictable results. Patterns exist and are identifiable, but they are random in both

their composition and connections creating unpredictable patterns. In contrast, closed systems, such as thermodynamics, are predictable and have constant energy and stability. The scientific community accumulates greater quantities of information in order to predict phenomena. For example, science can relate cause and effect to predict celestial movements of eclipses, moon phases, and sunrise and sunset; however, meteorological predictions of temperatures, precipitations, and storm conditions are limited. Although some systems are the sum of its parts, most systems are open and cannot be predicted through the accumulation of information. Since most systems are open and unpredictable, scientific thinking has gone through a revolution which affects many fields (Crutchfield, Farmer, Packard, & Shaw, 1986). Feigenbaum, a theoretical physicist, identified the universality of systems. That is, complexity has universal behavior in all systems. Feigenbaum constructed mathematical programs as proofs of the similarity of patterns in natural and human systems and so presented chaos theory to the scientific community. According to Crutchfield et al. (1986), the existence of chaos affects the scientific method itself.

Systems may exhibit varying degrees of simplicity or complexity. What may appear complex is often simple; in reverse, what may appear simple is often complex. For example, chaos has been found in complex systems such as the human heart and in simple systems such as a dripping faucet. Stability was thought to exist in both systems. However, the healthy heart beats randomly and the unhealthy heart beats consistently. The dripping faucet may appear regular with ordered droplets; yet randomness occurs at the micro level and unpredictable patterns occur. Therefore, both complex and simple systems exhibit randomness.

Order exists in random systems as chaos exists in stable systems. Chaotic systems appear random and fluid, yet they have underlying order and pattern (Ditto & Pecora, 1993). Natural and human systems depend on energy for sustenance; therefore, systems remain in dynamic equilibrium--the process of disequilibrium searching for equilibrium. When the system attains a nonhomogeneous, ordered state, that is the "order out of chaos" identified by Prigogine and Stengers (1984). What seems complex is simple and what seems simple is complex. What seems random is stable and what seems stable is random. What is locally unpredictable is globally stable. Since change is constant, systems are dynamic and unpredictable.

## Fractals

Mandelbrot's mathematical principle of self-similarity was modeled using computer-generated images of a coastline to show similar patterns at any scale. The resulting theory of infinity of patternization based on scale, in which macro and micro levels replicate one another, was proposed. Mandelbrot thus created the theory of fractals. What appears as a particular pattern exists despite the scale; that is, whether the scale is large or small, the pattern continues. Mandelbrot pursued other examples of fractals including price charts and river charts, in which patterns remain constant at various scales. Microscopic examination might identify random patterns whereas the macroscopic view might see unity and cohesion; or the reverse may be true. Therefore, chaotic patterns may exhibit order or disorder in surface structure or deep structure which may be stable or oscillating (Gleick, 1987).

Initial Effects

The "butterfly effect", the mathematical graphic of weather forecasting, shows pattern in the midst of unpredictability and, therefore, illustrates the dynamic chaos of initial states. Sensitivity to initial conditions suggests that almost identical systems will rapidly evolve into different systems even with small changes in the original states (Ditto & Pecora, 1993; Duit & Komorek, 1994). With change of the initial condition, change in the entire system may occur.

Bifurcations

Open, nonlinear systems fluctuate. When the fluctuation threatens the structure of the system at a far-from-equilibrium point, a bifurcation may occur. A bifurcation point is the threshold of stability which can branch in two or multiples (Loye & Eisler, 1987). Bifurcations are not predictable. Neither the critical point of change nor the direction of change can be determined in advance (Prigogine & Stengers, 1984). This feature is the chaos of the system. Chaos theory suggests near-equilibrium states may seem homogeneous, but when bifurcations occur they can be amplified to create far-from-equilibrium conditions. Over time, the bifurcation can create fragmentation leading to new systems or create its own stability through feedback loops.

## Applications of Chaos

Chaos theory has a body of knowledge comprised of theoretical elements including systems, fractals, initial effects, and bifurcations. Concepts such as nonlinearity, diversity, disorder, disequilibrium, instability, and unpredictability dominate the reading of chaos theory. Ideas such as irreversible processes create order, far-from-equilibrium conditions cause bifurcations, and entrophy causes growth, also dominate the literature. For chaos theory to be theoretically accepted with a body of knowledge requires a model which demonstrates applications.

Applications

Attempts to explain chaos delved into a variety of fields. The resulting applications of chaos theory to mathematical, chemical, and fluid models was possible before its application to other models in natural and human systems for a number of reasons, including the ability to create adequate models for study. One of its first applications was to the field of population biology, yet its expansion into other fields did not readily occur (Pool, 1989).

Chaos has been applied to natural and human systems. Evidence of the operation of chaos in natural systems includes weather patterns, fluid motion, and migratory movements. In addition, chaos has been applied to music performances, communication systems, and business management. Chaos may also be found in social systems of cultural diffusion, group interactions, and cognitive processes (Loye & Eisler, 1987).

> Chaos has already been applied to increase the power of lasers, synchronize the output of electronic circuits, control oscillations in chemical reactions, stabilize the erratic beat of unhealthy animal hearts and encode electronic messages for secure communications (Ditto & Pecora, 1993, p. 78).

Applications to history (multiple causation), geography (urban development), and economics (economic systems) are also beginning (Loye & Eisler, 1987). Chaos has been applied to diverse fields such as medicine and economics. "It appears to be for this reason no wonder that the chaos theory has become appealing for a number of other disciplines outside mathematics and science and has even gained considerable attention in a broader public" (Duit & Komorek, 1994, p. 52).

The idea of change and constant fluctuation as a natural, normal, and preferred condition became more acceptable when scientists discovered the human heartbeat is in a continuous state of random behavior and, when suffering an attack, becomes constant. The patterns of the heart demonstrate the importance of understanding chaotic behavior. Although precise predictions may not be possible, examination of patterns provide the order within chaos.

Criticisms of Chaos Applications

Chaos, with its computer-generated models and applications to natural and human sciences, is not accepted by all researchers. For instance, Kennedy (1994) suggests the broad application of chaos theory to geomorphology is inappropriate. Kennedy, as an example, cited equilibrium as a misused concept.

> Myself, I consider that Thorn and Welford, in their desire to see equilibrium as a key and central concept, have ignored the rather good evidence that there is actually a limited number of processes which may be demonstrated to produce definable equilibrium states. That this may be true does not seem to be a good, let alone a sufficient, reason to assume that all processes in the physical world must be desperately seeking equilibrium. Nor does importing the notion of the strange attractor from chaos theory appear to make the situation any simpler (Kennedy, 1994, p. 703).

Furthermore, Kennedy suggests chaos has limited utilitarian benefit, although in areas of climatic patterns, mechanics, and thermodynamics it has explanatory power.

Critics of chaos theory are challenging researchers to investigate applications more deeply and broadly. For example, Gao and Xia (1996) investigated the application of fractals to geomorphology in order to examine Kennedy's argument. Based on the researchers' extensive study of coastlines, drainage networks, surface roughness, landscape ecology, and topographic features, they found the linear model of fractal analysis was limited "because there is no one-to-one relationship between fractal dimensions and processes. The same landform may be shaped by different geomorphic processes occurring at various scales" (pp. 188-189). Thus, fractals do not necessarily apply to all geomorphologic features because of the profound influence of other variables.

> A regionalized geographic variable may be modeled linearly and also spherically, logarithmically and exponentially. The linear model that forms the foundation of fractal analysis thus accounts for a very small portion of all models. As Goodchild (1982) and Clarke (1988) demonstrated, the fractal model may only be valid for some special cases and captures only a certain component of the real world. Therefore, other models should not be abandoned, but should be used in conjunction with fractal analysis in physical geography (Gao & Xia, 1996, p. 189).

Chaos, then, applies to geomorphology and aids investigations of phenomena. At this time, however, particular aspects of chaos may not be applicable or may require redefinition. As a theoretical perspective in its infancy, chaos theory needs challenges to refine its tenants and provide applications.

Another criticism of chaos theory is its application to learning. According to Benson and Hunter, the application of chaos to learning negates theoretical constructs of teaching. "It classifies teaching as non-determinate behavior. It also renders it impossible to map teaching onto any general scientific theory designed to explain observations and relation in the physical world" (Benson & Hunter, 1993, p. 65) Furthermore, "chaos assumptions suggest learning is largely random and that it can reach a bifurcation point at any time" (Hunter & Benson, 1997, p. 95). Benson and Hunter believe chaos theory cannot be applied to human systems of learning where individual choices and decisions are part of complex cognitive thinking that crosses boundaries. Thus, applying the chaos of physical systems to human systems is reductionist; humans are complex and choose to respond differently than mechanistic systems. Furthermore, they suggest that the fallacy of applying mechanistic processes to learning in the past is being replicated by applying chaos theory to learning today. Instead, the researchers suggest social constructivism as an appropriate model for learning in which students actively construct meaning through social engagement.

> The chaoticists are committing a similar error of knowing. They choose to view education from a chaotic frame of reference and then conclude that chaos theory has <u>the</u> answers for education. Making this leap of logic work will require that the chaoticists demonstrate either that chaos theory is a grand theory which subsumes educational theory or that chaos theory is incommensurable with educational theory....In other words, proponents of a chaotic theory of education are obliged to demonstrate that chaos theory provides us with a clearer, more coherent and more consistent understanding of educational events than we have at present (Hunter & Benson, 1997, p. 93).

Benson and Hunter challenge researchers to present a comprehensive model of chaos in education and to address concepts of bifurcations and unpredictability and the role of individual decision-making.

## Classroom Applications

Prigogine and Stengers in their classic Order Out of Chaos presented a synthesis of chaos theory. By using common vocabulary and applying chaos to other fields, they brought cohesion to an ill-defined theory. Although applications of chaos theory have occurred in scientific fields, they are negligible in the social sciences and rare in education. The value of chaos theory in education, however, has been identified (Cronbach, 1988; Cziko, 1989; Doll, 1988; Salomon, Perkins, & Globerson, 1991), yet its applications have not been fully explored. Salomon et al. (1991) suggest that the application of chaos theory to the classroom enhances learning:

1. Chaos reinforces systemic approaches to human interactions;
2. Chaos encourages cultural diversity as beneficial and necessary;
3. Chaos reaffirms theoretical notions of intelligence as dynamically

multidimensional without linear progression;

4. Chaos confirms learning processes as fluid, dynamic, and nonlinear needing change, conflict, and diversity;
5. Chaos requires an evaluation which is patterned, flexible, and holistic to assess learning.

Classroom applications of chaos theory can be demonstrated by the elements of systems, fractals, initial effects, and bifurcations.

<u>Systems</u>

According to Leinhardt (1992) learning is not linear; it is multi-dimensional and dynamic. A pedagogical problem is how to transform what has been regarded as a linear process of knowledge acquisition with stable, component parts into a multifaceted, integrated system (Leinhardt, 1992). The classroom has traditionally been a closed system with defined boundaries, few variables, and predictable outcomes. This mechanistic, linear view neglects students as active constructors of meaning with diverse views, needs, and goals (Doll, 1987).

The classroom is an open, nonlinear, and chaotic system with unpredictable processes. Teachers respond to chaos by categorizing and standardizing to reduce instability and to increase predictive behaviors. Cronbach (1989) suggests that as educators we seek understanding; we reduce and consolidate to discover order, and we deny irregularity and claim it is random. Such "noise" or errors are valuable for learning. Noise "is any influence that causes the system to wander randomly among its possible states" (Brooks & Wiley, 1988, p. 70). Noise was ignored and labeled error in scientific research. In chaos theory, errors are healthy to the analysis of a system. In education, errors create patterns of learning. The quest for stability ignores the nature of learning as a multifaceted, dynamic system with broad, interrelated patterns.

> The cognitive system is an open system which interacts with the medium by receiving information and producing answers....The fact that it is a system open to the influence of numerous variables (motivation, information, conceptual structure, etc.) as well as the loss of information (given the characteristics of its reception, transmission & codification), makes the cognitive system what Prigogine & Stengers (79) call a far from equilibrium system...."Non-linearity" is the result of the interaction of two opposite forces: the conceptual schema itself which tends to stability by offering resistance to change and the new information input that causes instability and activates conceptual change (Gleick, 1987, pp. 306-307).

The classroom, then, is an open, non-linear system. It is characterized by a variable range of complexity, instability, and unpredictability.

<u>Fractals</u>

Learning occurs at various scales. As Cronbach (1988) suggests, information is acquired and lost at different scales. Cognitive processes occur by understanding patterns of interrelated concepts embedded in other interrelated patterns. Individual learning is variable and unpredictable, potentially resulting in chaos in the classroom with students at various levels of learning, demonstrating multiple scales of understanding.

In addition, the complexity of individual decision-making is reflected in the complexity of the classroom and the school. Variations in individual behavior are unpredictable, yet patterns occur which are similar at individual, group, and institution levels. Similarity within scales means the individual, classroom and school can be characterized by similar patterns determined by characteristics of systems, initial effects, and bifurcations.

## Initial Effects

Cognitive researchers acknowledge the role of prior learning to create understanding. Indeed, prior knowledge creates conditions necessary for learning. Since learning is sensitive to initial conditions (McWhorter, 1993), small disturbances during processing may result in totally different behavior (Duit & Komorek, 1995).

> Thus the concept of chaos assumes particular importance for educational research...in that it provides a model for understanding how even infinitesimally tiny initial differences in any of a multitude of factors (e.g., teacher attention, teaching materials, motivation, home background, student background knowledge) could in the course of time lead to significantly and totally unpredictable differences in outcomes (Cziko, 1989, p. 19).

Learning can be considered chaotic because, although pre and post scores of achievement can be calculated, they cannot be predicted for individuals. That is, given the same pretest score, posttest scores may be appreciably different. "No matter how reliable and valid a test may be, identical scores on a pretest will inevitably lead to unpredictable differences on a posttest of later achievement" (Cziko, 1989, p. 19). Furthermore, the normal curve of classroom performance presents boundaries and tendencies. A pattern at the macroscopic level may hide the chaos at the microscopic level. Thus, slight changes in initial states may greatly affect individual learning.

## Bifurcations

Educational researchers have explained the unpredictability of bifurcations and the role of individual decision-making in classroom learning. Not only can teachers control learning, but students can as well; both teachers and students may resist bifurcations. Stability is sought through maintenance of equilibrium and avoidance of challenge. Learners have cognitive strategies that are effective "but ones adapted to goals different from those of the curriculum, such as avoiding unproductive effort and minimizing damage to self-esteem--goals bound to have a high priority for any reasonable person" (Scardamalia, 1994, p. 203). Learners avoid thinking about challenging, complex, abstract information. They tend to accept evidence consistent with their prior beliefs, but distort or ignore evidence to protect beliefs, maintain control, or provide stability for their thinking (Schauble, Klopfer, & Raghaven, 1991). Bifurcations are minimized and stability rather than flexibility in thinking is sought.

> Where prior beliefs and instruction are incompatible, it is rare for resolution of contradictions to occur; nor does one proposition win out over the other. Rather, both views are stored in memory. This schizophrenic state of knowledge causes students little trouble, as the teacher's statements are recalled in the context of the classroom and school-type tests and the experience-based self-constructed knowledge in the context of the everyday life (White & Gunstone, 1992, p. 79).

The introduction of chaos theory into the classroom may relieve students' and teachers' concerns of intellectual and behavioral instability.

In equilibrium or stability, bifurcations or transformations may not occur; but when cognitive thinking is in a far-from-equilibrium system, learning occurs (Luffiego, Bastida, Ramos, & Soto, 1994). Prior knowledge is stable and resists change while new knowledge "causes instability and activates conceptual change" (Luffiego et al. 1994, p. 307).

> This critical point varies from individual to individual, is not predictable, and needs both internal development and disequilibrium to be effective. At this critical point (termed "bifurcation" by Prigogine) various pathways of development are possible. Which one occurs will depend on how the individual interacts with the recognized perturbations. The teacher's task then changes from presenting perturbations to supporting reconstructions in a cooperative and caring way (Doll, 1986, pp. 15-16).

Chaos is not disorder, but unpredictability. As prior knowledge or the initial state changes, numerous variables interact to produce a new unpredictable state. The critical point of the learning process is the juncture or bifurcation of disequilibrium. The significant moment is the "aha!" of learning--the sudden comprehension or understanding of a novel relationship.

## Conclusion

Chaos theory can be applied to the classroom. Learning occurs in nonlinear, complex systems at unpredictable bifurcation points for each learner. Furthermore, small differences in the initial condition give rise to unpredictable results (Cziko, 1989). Moreover, Cronbach (1988) suggests cognitive thinking entails various scales in which information can be lost or gained. Learning, then, is chaotic because it occurs in open systems, has unpredictable bifurcation points, the initial states affect learning, and the process replicates at different scales.

Applications of chaos theory to teaching and learning have been primarily limited to the sciences. For example, a study by Duit and Komorek (1994) found physics students could understand the fundamentals of chaos theory when learning about elementary prediction. The use of schematic models and analogies led tenth graders to understand limited predictability in simple systems, such as a pendulum and dice. Although attempts to create lessons for teaching are few and found mainly in science (Duit & Komorek, 1994), it is expected that applications will expand to mathematics and other subjects, such as reading (Robinson & Yaden, 1993) and literature (Zeitz, 1994) and in areas of school improvement (Stanford, 1996).

The Newtonian model of the natural world as linear, stable, sequential, and orderly cannot be conceptually applied to human interaction patterns. Investigations have shown that the natural world is more than the sum of its dissected parts. This is also true with human interactions and learning. Education is multifaceted and dynamic. Although its components have been assessed separately (such as curriculum, instruction, and student performance), understanding the dynamic interrelationship of the whole is necessary (Crowell, 1989; Cziko, 1989). "We have separate subjects, separate skills, separate objectives, separate evaluations, segmented continuums, linear methods, behavioral techniques, and isolated

classrooms" (Crowell, 1989, p. 61). Therefore, a model of learning is needed. Although several theoretical perspectives are available, chaos has much to offer.

> Although apparently still unknown by most (if not all) social and behavioral scientists, chaos has very important implications for the predictability of human behavior and educational research because it holds that even though the relationship between two variables may be both quite simple and completely deterministic, a nonlinear relationship may nevertheless lead to outcomes that are entirely unpredictable (Cziko, 1989, p. 19).

According to researchers (Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987), the oversimplification of complex learning has led to learners' lack of understanding and the development of misconceptions. The researchers recommend learning and instruction focus on multiplicity; that is, multiple structures and strategies for learning are needed.

> Instead of using a single knowledge structure, prototype, analogy, and so on, multiple knowledge precedents will need to be applied to new situations (multiple schemas, several past cases, overlapping analogies). Under conditions of ill-structured complexity, single approaches provide insufficient coverage (Spiro et al. 1987, p. 184).

A multiple and flexible approach to classroom learning may address the complexity of learning. The researchers conclude that complexity cannot be explored through the pursuit of one knowledge structure; a closed system will occur instead of an open system resulting in a narrow vision of one particular aspect of learning. "We know of no area of human endeavor that lacks an ill-structured aspect. Success in ill-structured areas tends to come only with a considerable accumulation of actual case experience" (p. 197). Such case experiences of learning have not been developed. Therefore, numerous case studies are needed to explore educational applications of chaos theory and, as a result, develop models for learning.

## Models of Learning

### Models

Although chaos theory has been evolving for years, computer technology has created an explosion in theoretical constructs, particularly in mathematics and the sciences. Chaotic systems were recognized in meteorology (Edward Lorenz), mathematics (Benoit Mandelbrot), and physics (Mitchell Feigenbaum). Investigators used computer graphics to create visual patterns based on mathematical calculations. These representations provide the basis of model building.

The development of a simple model of chaos has led down many corridors. One model is the catastrophe theory and its bifurcation diagram (Devaney, 1987). This model uses folds to identify bifurcation points. Another model is Allen's (1988) linear model of bifurcation and discussion of chaotic systems. Allen's focus was not to create a model which demonstrates chaotic systems; rather, he sought to illustrate the construction of models as a necessary but limited expression of the system. Creating a single model to illustrate systemic change and unpredictability is challenging. Moreover, Stanford (1996) suggests a model would be so complex, it becomes not

only difficult to construct, but perhaps useless. However, Prigogine and Stengers (1984) developed a model with three stages linking natural and human systems through a process of equilibrium (steady state), disequilibrium (oscillations), reequilibrium (chaos). This model reflects Piaget's educational theory.

Piagetian Theory. The learning process is a chaotic system of equilibrium-disequilibrium-reequilibrium as found in Piaget (Doll, 1988). Equilibration is used to explain cognitive development as a series of changes from one stage to another. According to Piagetian theory, the learner passes through stages of cognitive development by experiencing discontinuity with current knowledge structures. The disequilibrium provides the impetus to transcend one stage of cognitive development to another. The process of gaining equilibrium is the acceptance of the unfamiliar as familiar (Juckes, 1991). "It is interesting to note that Jean Piaget in his equilibrium-disequilibrium-reequilibration model, also places emphasis on introducing chaos into the developmental process" (Doll, 1988, p. 120).

The Piagetian stage process can be described at the individual learner level. The learner experiences disequilibrium when learning; such incongruity, the change in understanding, leads to new learning. This disequilibrium is new knowledge which must be constructed onto prior knowledge structures. The stability of previous knowledge is challenged. When naive prior learning is activated and challenged, learning occurs. It is the imbalance, the cognitive dissonance, which causes cognitive development. After the occurrence of assimilation (integrating new information with prior learning) or accommodation (modifying new information to correlate with prior learning), the knowledge structure experiences reequilibrium and achieves a state of temporary stability. This is the bifurcation of learning.

Cognitive development, then, occurs by spurts at points of bifurcation or disequilibrium. Doll (1989) quoted Piaget: "However the nonbalance arises, it is the driving force of development....Without the nonbalance there would not be 'increasing reequilibration' (1977, p. 13)" (Doll, 1989, p. 67). Learning, then, occurs at points far-from-equilibrium. According to Piaget, cognitive equilibration is a positive, constant process of learning which occurs at the transitory points in disequilibrium (Acredolo & O'Connor, 1991). The transition process, then, is a lengthy constructive process of spontaneous reorganization.

Piagetian assimilation and accommodation are closely linked with the spontaneous reorganization of thinking, although teachers can structure learning so students spontaneously reorganize their thinking to achieve greater complexity and flexibility (Lawson, 1994). The teacher initiates disequilibrium and provides numerous examples in novel situations over an extended time period to allow for equilibration. Thus, Piaget's stages of cognitive development are related to the process of growth in cognitive abilities and an increase in abstract thinking.

Theoretical Models. Current curriculum theories do not explain and predict learning. A behavioralist perspective of curriculum is restrictive of educational development. The behavioralist, product-process perspective, focuses on student passivity, stability, linear thinking, and order. When focusing on linear thinking processes, learning becomes restrictive. Behavioralists cannot predict learning when

variables are uncontrolled; that is, a diverse environment or heterogeneous population may generate conditions in which results of curriculum and instruction cannot be anticipated. Whitson (1988) suggests that a sequential developmental hierarchy, such as Bloom's taxonomy of objectives, also does not create learning. Thus, information processing does not adequately represent learning. The teacher structures learning with objectives clarified, an anticipatory set and closure, and learning objectives established as a feedback loop. This linear perspective of learning as supported by Hunter and Tyler, ignores students' construction of meaning (Doll, 1987).

Constructivist theory, accepted by cognitive psychologists, proposes learners actively construct meaning through the interaction of prior learning, new information, and the context of learning (Bruning, Schraw, & Ronning, 1995). Prior knowledge is the initial state that creates conditions for learning. Vygotsky's zone of proximal development is the point at which learning occurs; that is, the bifurcation occurs at the level of difficulty allowing the learner to understand new information independently (Bruning et al. 1995). Learning, then, is a dynamic constructive process in the ongoing equilibration process (Metz, 1995).

Critics of constructivism challenge its utility as a theory to explain and predict. Osborne (1996) suggests constructivism is not a scientific theory, although it is valuable for modifying instructional strategies and understanding learning. Osborne argues that researchers cannot uncritically accept constructivism as theory, although as methodology it has achieved powerful and important results. Furthermore, Osborne states that constructivism lacks rigor because it does not explain or predict learning or performance.

From a postmodernist perspective, learning is transformative. It is developed through the transformation of students' understanding rather than incrementally with students' acquisition of information.

> A transformatory curriculum, a theoretical paradigm, is based on chaos theory. Theorists such as Dewey, Piaget, and Bruner have worked on developing a new educational model–one based on an open system concept--but until the social sciences accept a new paradigm it is almost impossible for education to develop one. However, work on such a model can contribute to a changed paradigm (Doll, 1987, p. 14).

The social sciences are seeking methods to understand models and apply theories to predict and, thereby, control the future (Loye & Eisler, 1987). Chaos needs further theoretical research and application to be accepted in the social sciences (Pool, 1989)

Doll believes a post-modern curriculum should be transformatory which "will accept the student's ability to organize, construct, structure, and will emphasize this ability as a focal point in the curriculum....Here curriculum becomes a process of development rather than a body of knowledge to be covered or learned" (Doll, 1987, p.18). Doll suggests four characteristics of a transformative curriculum. First, the curriculum must be rich in depth and breadth to encourage the generation of meaning; "that is, it needs to be filled with enough ambiguity, challenge, perturbation to invite the learner to enter into dialogue with the curriculum and with those working in the curriculum" (Doll, 1993, p. 287). The second characteristic of a transformative curriculum is recursion, or the ability to reflect and reexamine curriculum tenants. Third, the curriculum has relations or interrelations among a few core ideas. Fourth,

the curriculum has rigor or a strong coherence among ideas. "A transformative curriculum focuses on the qualitative changes the participants--teachers as well as students--go through as they engage in the curriculum" (Doll, 1988, p. 127). Prigogine's curriculum is also transformative as it creates paradigm shifts; it qualitatively allows new learning through bifurcations (Doll, 1988). Therefore, the teacher must create bifurcations or cognitive dissonance to motivate students to reorganize prior knowledge.

Conclusion

According to Stanford (1996), curriculum models are emerging to connect curriculum, instruction, and assessment using chaos as an organizer. In the CHART program to improve curriculum and instruction in the humanities, the characteristics of a self-organizing educational system were identified. First, it has an open, interacting, consuming system; second it has self-organization by components; third it has resistance to change; and fourth it has adaptability and system reorganization.

> The theory of self-organizing systems suggests that the quest for a process that will predictably transform school systems is comparable to the quest of alchemists for a process that would transform lead into gold....The theories of the new paradigm do not promise answers, but simply help us see patterns more effectively (Stanford, 1996, p. 265).

The evolution of the CHART model, both the product and the process, reflected the value of educational patterns and the problems of model construction. Stanford (1996) concluded that evolution of a chaos model for education may depend on inclusion of chaos characteristics and commitment of classroom teachers. Results of the CHART program led to conclusions that creating an educational model of chaos theory is not as desirable as identifying patterns that can be addressed by the theory.

## Conclusion

More important than a model is the development of a perspective which encompasses both the theory and its applications (Prigogine, 1989). Additional studies are obviously needed to explore the application of chaos theory to classroom learning before a satisfactory model can be constructed. As educators become acquainted with chaos theory, further research studies can be expected.

The educational model may be formed from one theoretical perspective or the unification of several theories (Derry, 1996). That is, Piagetians may elaborate on processes of assimilation and accommodation. Constructivists may propose active construction of meaning (Benson & Hunter, 1993). Theorists may present the transformative curriculum (Doll, 1993). The education model which represents chaos in education will undergo substantial scrutiny. As with the CHART program (Stanford, 1996), it is perhaps more effective to explore applications of chaos before presentation of a theoretical model.

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